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ENDURANCE TEST ON FLEXIBLE STEEL WIRE ROPE FOR AIRCRAFT CONTROLS AT VARIOUS PULLEY/ROPE DIAMETER RATIOS

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AQD Development Report

Endurance Test on Flexible Steel Wire Rope for Aircraft Controls at various Pulley/Rope Diameter Ratios

by

H A Senior & A New

Summary

During previous investigations into the endurance properties of flexible steel wire rope for aircraft controls, large losses in strength were noted when small test pulleys were used. In view of this, a programme of tests has been carried out to investigate the effects of test pulley size on the endurance of 1/8" diameter carbon and corrosion resistant steel ropes. A range of test pulley/rope diameter ratios between 7 and 30 has been investigated and the results of these tests are given in the report. The indications are that pulley to rope ratios of the order of 20 to 1 are desirable to ensure good endurance properties.

The report also shows that under the particular conditions of test used (ie room temperature) corrosion resistant steel showed the better endurance properties.

Approved by ..H. Gregory....

Head of AQD Laboratories

on behalf of Director, Aeronautical Quality Assurance Directorate

1 Introduction

1.1 During endurance testing of flexible steel wire rope for aircraft controls a considerable loss of strength was observed when the ratio of pulley diameter to rope diameter was small.

1.2 The effect was particularly noticed during tests to compare the performance of two different types of endurance testing machine (Report No AQD/D18) as follows.

(a) An American design as stipulated by the American Military Specifications W1511 and C5424

(b) A new testing machine developed at AQD Laboratories

The American method specified for 1/8" diameter rope required the use of small test pulleys, ie a pulley/rope diameter ratio of 7, and under this condition most of the ropes tested failed to meet the specification requirement. Tests on the same rope samples by the AQD method which used a larger ratio, however, invariably showed good properties.

1.3 It appeared possible that the American conditions of test for 1/8" diameter carbon steel rope were unrealistic and could result in the rejection of rope with good endurance properties. Therefore investigation, to study the effects of a range of test pulley sizes, was undertaken.

2 Test Conditions

2.1 Two samples, each 1000 metres in length of 1/8" diameter wire rope were obtained from a British rope manufacturer. One of these samples was carbon steel to MIL specification W1511A (Amendment 4) and the other corrosion resistant steel to MIL specification C5424A; details of the rope manufacturer's production test results are given in Table 1.

2.2 Preliminary work indicated that the corrosion resistant steel rope had much better endurance properties than the carbon steel. In order to obtain a realistic reduction in strength, therefore, it was necessary to increase the number of cycles to which the corrosion resistant steel was subjected. However to provide a direct comparison of the two materials a small series of tests of the corrosion resistant material at conditions similar to those for the carbon steel was also undertaken.

2.3 128 test lengths were cut from each sample to provide 16 test lengths, randomly selected for each of 8 different test conditions. Additionally a further 32 test lengths were cut from the corrosion resistant sample to provide material for the comparison test at 2.2 above. Each test length was further divided, one part being used to determine initial breaking strength and the other for endurance testing.

2.4 The range of test pulley diameter used for both materials was 0.875, 1.188, 1.563, 1.875, 2.500, 3.125 and 3.750 inches, ie 7, 9.5, 12.5, 15, 20, 25 and 30 times the rope diameter.

2.5 All the carbon steel endurance specimens were tested for 36,000 cycles (72,000 reversals). They were held at a tension of 6% of the minimum breaking strength and ran at 100 cycles per minute; this tension is considered representative of aircraft practice. Tests on the corrosion resistant steel rope, however, were increased to 72,000 cycles (144,000 reversals). The direct comparison between the two materials was obtained by two test series on corrosion resistant rope using pulley diameters of 0.875 and 2.5 inches, ie ratios of 7 and 20, at 36,000 cycles to correspond with similar tests already included in the range for carbon steel.

2.6 Finally a test series to the standard conditions of the AQD method is pulley/rope ratio diameter 18, tension 12% of the specified breaking load and 36,000 cycles at 100 cycles per minute, was carried out on each rope sample. These test series provided comparison of endurance properties with those tested in earlier programmes in which the higher tension is suggested to give rapid results.

2.7 The breaking strength of each test specimen was found, both before and after endurance testing, and the loss of strength calculated individually for each.

2.8 The results of the tests are given in Tables 2, 3, 4, 5 and 6, the range and mean value for each series being quoted.

2.9 The test results are also given in diagrammatic form, firstly, as histograms showing the actual distribution of results and compared with the normal distribution curves calculated from the standard deviations for each of the test series and secondly, as graphs in which the mean loss of strength is plotted against the pulley/rope diameter ratio; figures 1-9 refer.

2.10 The AQD endurance testing machine, type 2, was used for all the endurance tests covered by this report, and this machine is illustrated at Figure 10.

3 Analysis of Results

3.1 The tests covered by this report show that the loss of strength of carbon steel rope when tested at a pulley/rope diameter ratio of 7 is 3 times that loss of strength when tested at a ratio of 9.5. The comparable figures for the corrosion resistant steel rope do not show quite such a pronounced increase but the loss of strength at a ratio of 7 is still more than double that at a ratio of 9.5.

3.2 The graphs at Figures 4 and 8 show the changes in loss of strength for all the various pulley/rope diameter ratios for the two materials and these indicate that a reasonably low loss of strength is only achieved when these ratios approach 20. Comparison of the loss of strength values at the ratio of 7 with those at this higher ratio of 20 show an increase of more than 13 times for the carbon steel rope and almost 4 times for the corrosion resistant steel rope.

3.3 It may be noted that the carbon steel rope series of tests showed a higher scatter in results at the lowest pulley/rope ratio.

3.4 The shallow wrap angle of the rope over the test pulleys may not often occur in practice but has been found to provide a rapid loss of strength and is therefore the method adopted in the AQD system. The use of hardened steel test pulleys may also have some effect on the rope life. Furthermore the programme has dealt only with two rope samples. Despite these aspects, it is considered that the investigation has shown that a large pulley/rope diameter ratio is essential if a long control rope life is to be achieved. The graphs suggest a desirable minimum of 20 to 1 and larger ratios may give further improvement.

3.5 The first issue of the American Military specifications W1511A for carbon steel wire rope required endurance tests over test pulleys whose diameter to rope diameter ratios was 9.5, but a subsequent amendment now requires a ratio of 7 for ropes of 1/8" diameter and less. This change of ratio has also been incorporated in the latest issue of the specification for corrosion resistant steel wire rope MIL C 5424 B. Previous test programmes suggested that this low ratio was too severe and this investigation tends to substantiate this conclusion.

TABLE 1 MANUFACTURER'S PRODUCTION TEST VALUES

Endurance test conditions:-

Carbon Steel wire rope 1/8 inch diameter
MIL Specification W1511A (Amendment 4)
Pulley/rope diameter ratio - 7
Number of reversals - 70,000 (35,000 cycles)
Oscillating rate - 120 reversals/minute (60 cycles/minute),
Rope tension - 10 lb.

Corrosion resisting steel wire rope 1/8 inch diameter
MIL Specification C 5424A
Pulley/rope diameter ratio - 9.5
Number of reversals - 150,000 (75,000 cycles)
Oscillating rate - 120 reversals/minute (60 cycles/minute)
Rope tension - 10 lb.

MATERIAL		Breaking Strength Before Endurance Test		Breaking Strength After Endurance Test		Loss of Strength
		lb	N	lb	N	Per Cent
CARBON STEEL	Test Values Obtained	2,342	10,418	1,299 1,164	5,778 5,178	44.5 50.3
	Spec Requirement	2,000	8,900	1,000	4,450	
CORROSION RESISTING STEEL	Test Values Obtained	2,307	10,260	2,105 2,128	9,364 9,466	8.7 7.7
	Spec Requirement	1,760	7,830	950	4,230	

TABLE 2 BREAKING STRENGTH RESULTS ON WIRE ROPES BEFORE ENDURANCE TESTING

MATERIAL	Number of Specimens Tested	Mean Breaking Strength daN	Breaking Strength Range daN	Standard Deviation daN	Coefficient of Variation %	Histogram Fig
Carbon Steel	128	9.57	9.10 to 9.90	12.8	1.3	1
Corrosion Resisting Steel	160	9.68	8.77 to 10.05	21.3	2.2	5

TABLE 3 ENDURANCE TEST RESULTS AT VARIOUS PULLEY/ROPE DIAMETER RATIOS

Carbon Steel Rope

Conditions of test:- Number of cycles 36,000 (72,000 reversals)
Cycling rate 100 cycles/minute (200 reversals/minute)
Rope tension 6% of the specified breaking strength ie 6% of 2000 lb = 54 daN
Wrap angle over test pulley 15°

Pulley/rope diameter ratio	Mean loss* of Strength Per Cent	Loss of Strength° Range Per Cent	Standard Deviation Per Cent	Histogram Fig
30	1.0	+2.4 to 4.7	2.0	2
25	2.4	0 to 6.6	1.7	2
20	2.4	+0.8 to 14.1	3.5	2
15	5.1	0.5 to 10.4	2.7	2
12.5	10.7	0.5 to 19.9	5.8	3
9.5	12.4	2.8 to 22.8	5.5	3
7	37.8	27.5 to 57.4	9.0	3

*NOTE: Although the results columns 2 and 3 are headed 'Mean loss of Strength' and 'Loss of Strength Range' it was found that many of the specimens tested showed a slight increase in strength after endurance. In each instance where this occurred the values quoted are prefixed by a positive sign.

TABLE 4 ENDURANCE TEST RESULTS AT VARIOUS PULLEY/ROPE DIAMETER RATIOS

Corrosion Resisting Steel Rope

Conditions of test:- Numbers of cycles 72,000 (144,000 reversals)
Cycling rate 100 cycles/minute (200 reversals/minute)
Rope tension 6% of the specified breaking strength ie 6% of 1760 lb = 47 daN
Wrap angle over pulleys 15°

Pulley/rope diameter ratio	Mean Loss* of Strength Per Cent	Loss of Strength* Range Per Cent	Standard Deviation Per Cent	Histogram Fig
30	3.6	0.5 to 8.4	2.0	6
25	2.0	+3.1 to 9.5	3.5	6
20	3.4	+9.3 to 16.5	8.0	6
15	1.2	+8.3 to 5.7	3.2	6
12.5	4.4	0.5 to 10.0	2.2	7
9.5	5.7	+1.6 to 10.9	3.5	7
7	14.0	5.4 to 23.2	5.8	7

*See note below Table 3.

In addition two test series, using test conditions identical with those used for the carbon steel, except for cable tension, were carried out on the corrosion resisting steel rope. The results of the tests are given in Table 5 below.

TABLE 5

Condition of test:- Number of cycles 36,000 (72,000 reversals),
Cycling rate 100 cycles/minute (200 reversals/minute)
Rope tension 6% of the specified breaking strength ie 6% of 1760 lb = 47 daN
Wrap angle over pulleys 15°

Pulley/rope diameter ratio	Mean loss* of Strength Per Cent	Loss of Strength* Range Per Cent	Standard Deviation Per Cent	Histogram Fig
20	0.1	+2.9 to 4.1	2.1	9
7	4.3	0.8 to 10.1	2.8	9

*See note below Table 3.

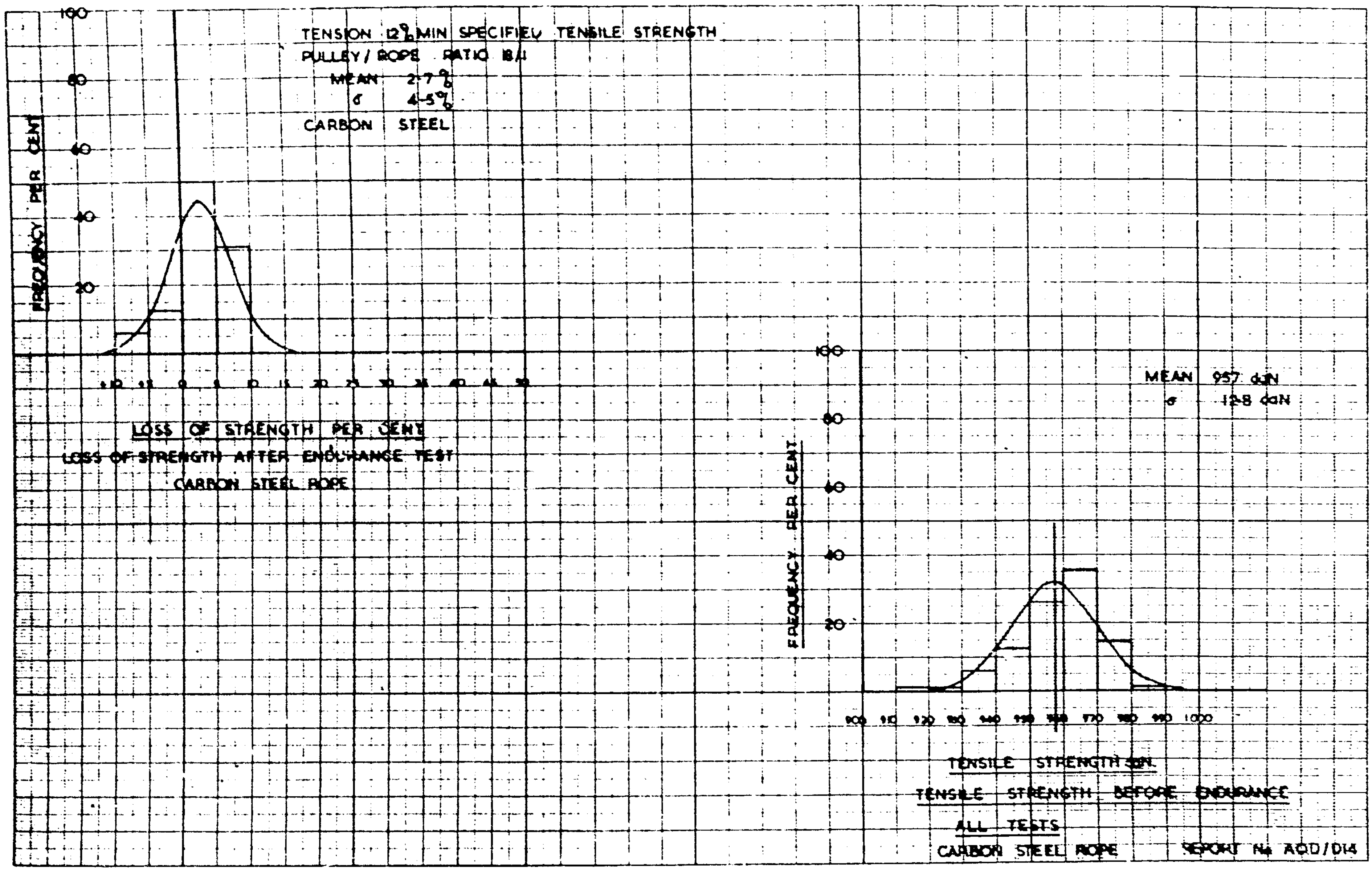
TABLE 6 ENDURANCE TEST RESULTS WHEN ROPES TESTED AT THE STANDARD CONDITIONS OF THE AOD METHOD

Carbon and corrosion resisting steel wire rope

Conditions of test:- Pulley/rope diameter ratio 18
Number of cycles 36,000 (72,000 reversals)
Cycling rate 100 cycles/minute (200 reversals/minute),
Rope tension 12% of the specified breaking load, ie 12% of 2000 lb - 107 daN for carbon steel and 12% of 1760 lb = 94 daN for corrosion resisting steel

Material	Mean loss* of Strength Per Cent	Loss of Strength* Range Per Cent	Standard Deviation Per Cent	Histogram Fig
Carbon Steel	2.7	+5.5 to 9.2	4.5	1
Corrosion Resisting Steel	+0.7	+5.0 to 3.0	2.3	5

*See note below Table 3



TENSION 12% MIN SPECIFIED TENSILE STRENGTH
PULLEY / ROPE RATIO 18/1
MEAN 2·7%
σ 4·5%
CARBON STEEL
FREQUENCY PER CENT
LOSS OF STRENGTH PER CENT
LOSS OF STRENGTH AFTER ENDURANCE TEST
CARBON STEEL ROPE
MEAN 957 daN
σ 12·8 daN
FREQUENCY PER CENT
TENSILE STRENGTH daN
TENSILE STRENGTH BEFORE ENDURANCE
ALL TESTS
CARBON STEEL ROPE
REPORT No AOD/D14

FIG. 1.

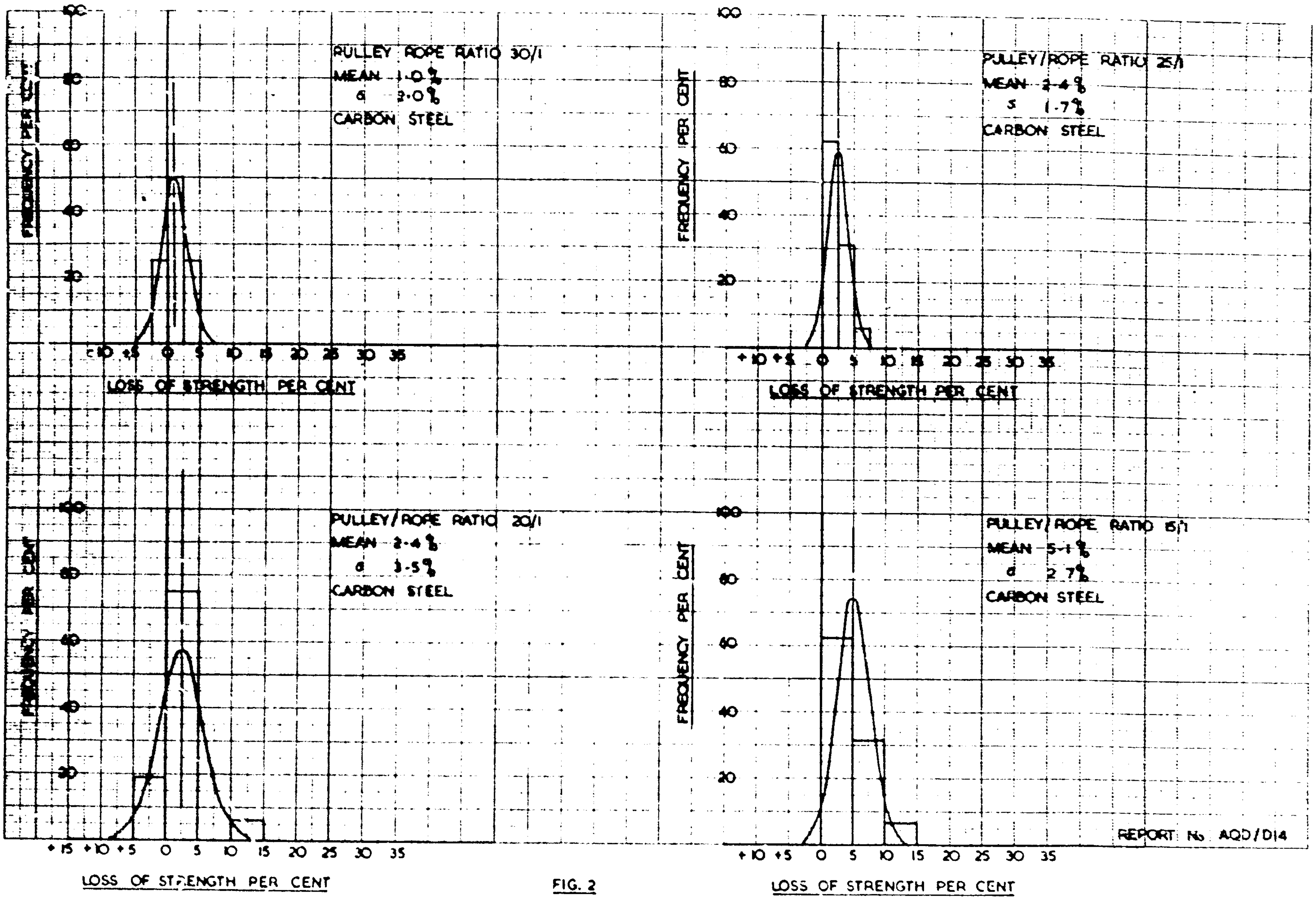


FIG. 2

REPORT No. AQD/D14

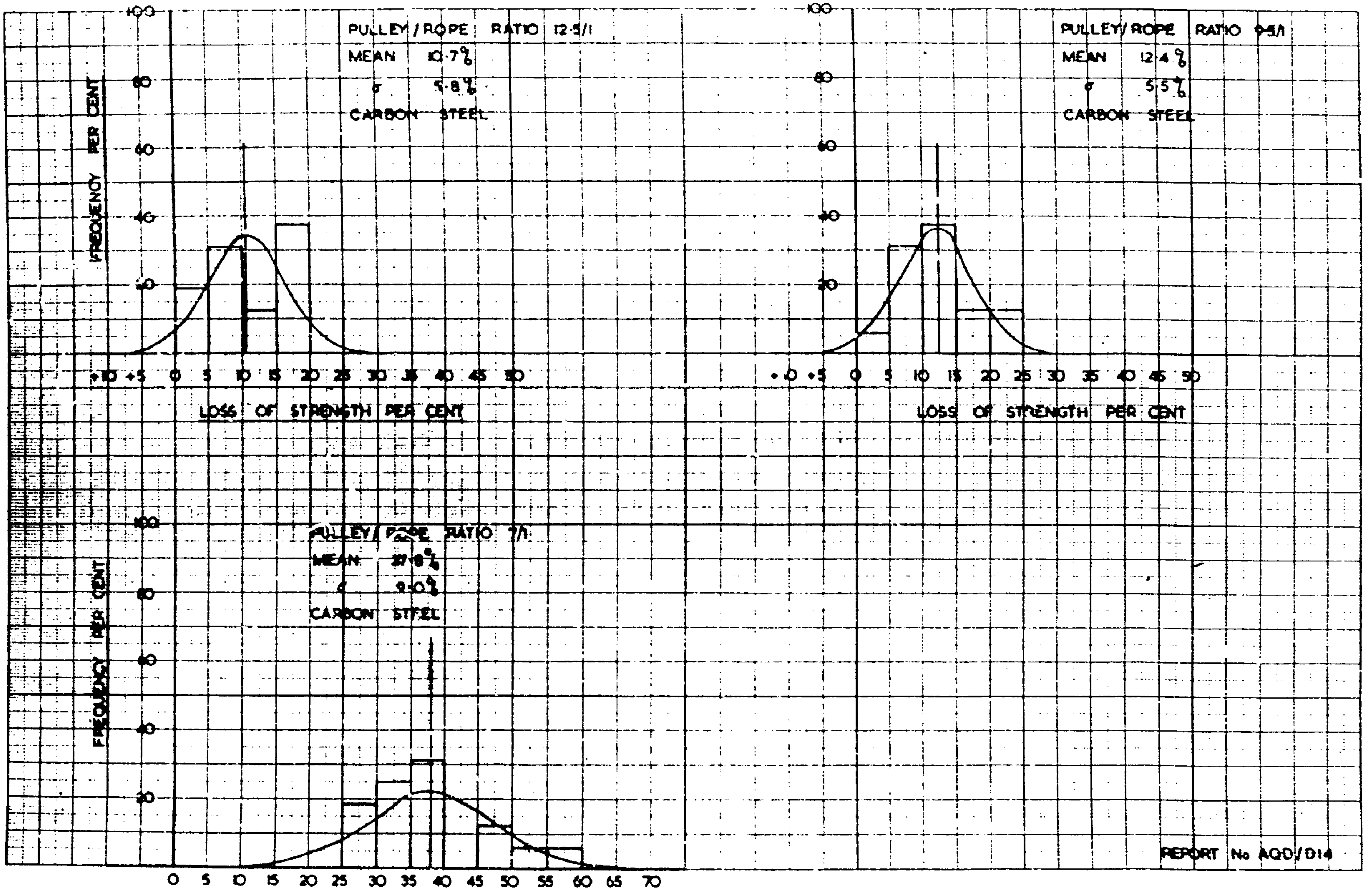
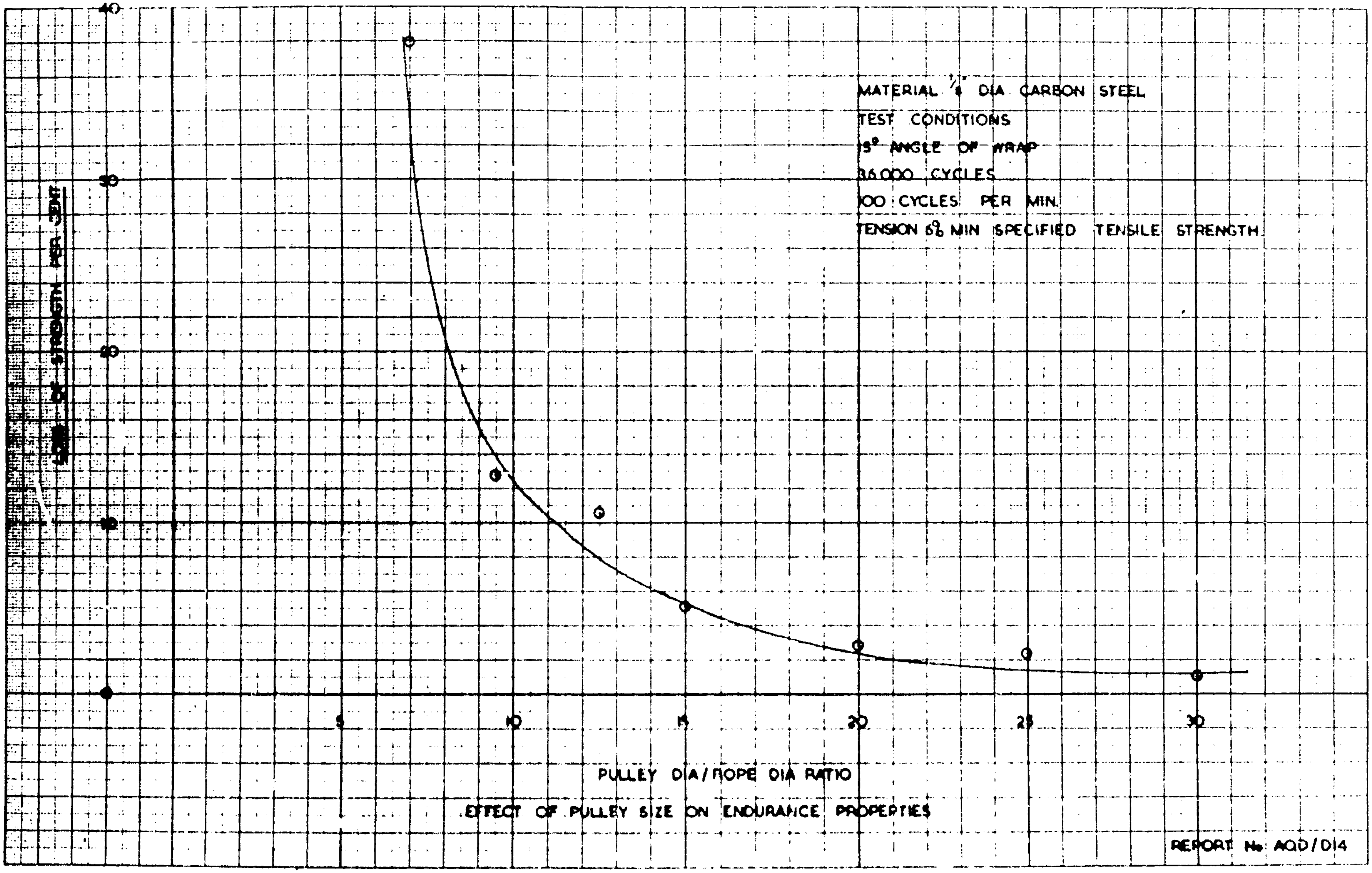

PULLEY / ROPE RATIO 12·5/1
MEAN 10·7%
σ 5·8%
CARBON STEEL
FREQUENCY PER CENT
LOSS OF STRENGTH PER CENT
PULLEY / ROPE RATIO 9·5/1
MEAN 12·4%
σ 5·5%
CARBON STEEL
LOSS OF STRENGTH PER CENT
PULLEY / ROPE RATIO 7/1
MEAN 37·8%
σ 9·0%
CARBON STEEL
FREQUENCY PER CENT
LOSS OF STRENGTH PER CENT
REPORT No AQD/D14

FIG. 3.



MATERIAL 1/2" DIA CARBON STEEL
TEST CONDITIONS
15° ANGLE OF WRAP
36,000 CYCLES
100 CYCLES PER MIN.
TENSION 6% MIN SPECIFIED TENSILE STRENGTH
LOSS OF STRENGTH PER CENT
40
30
20
10
5
10
15
20
25
30
PULLEY DIA/ROPE DIA RATIO
EFFECT OF PULLEY SIZE ON ENDURANCE PROPERTIES
REPORT No AQD/D14

FIG 4.

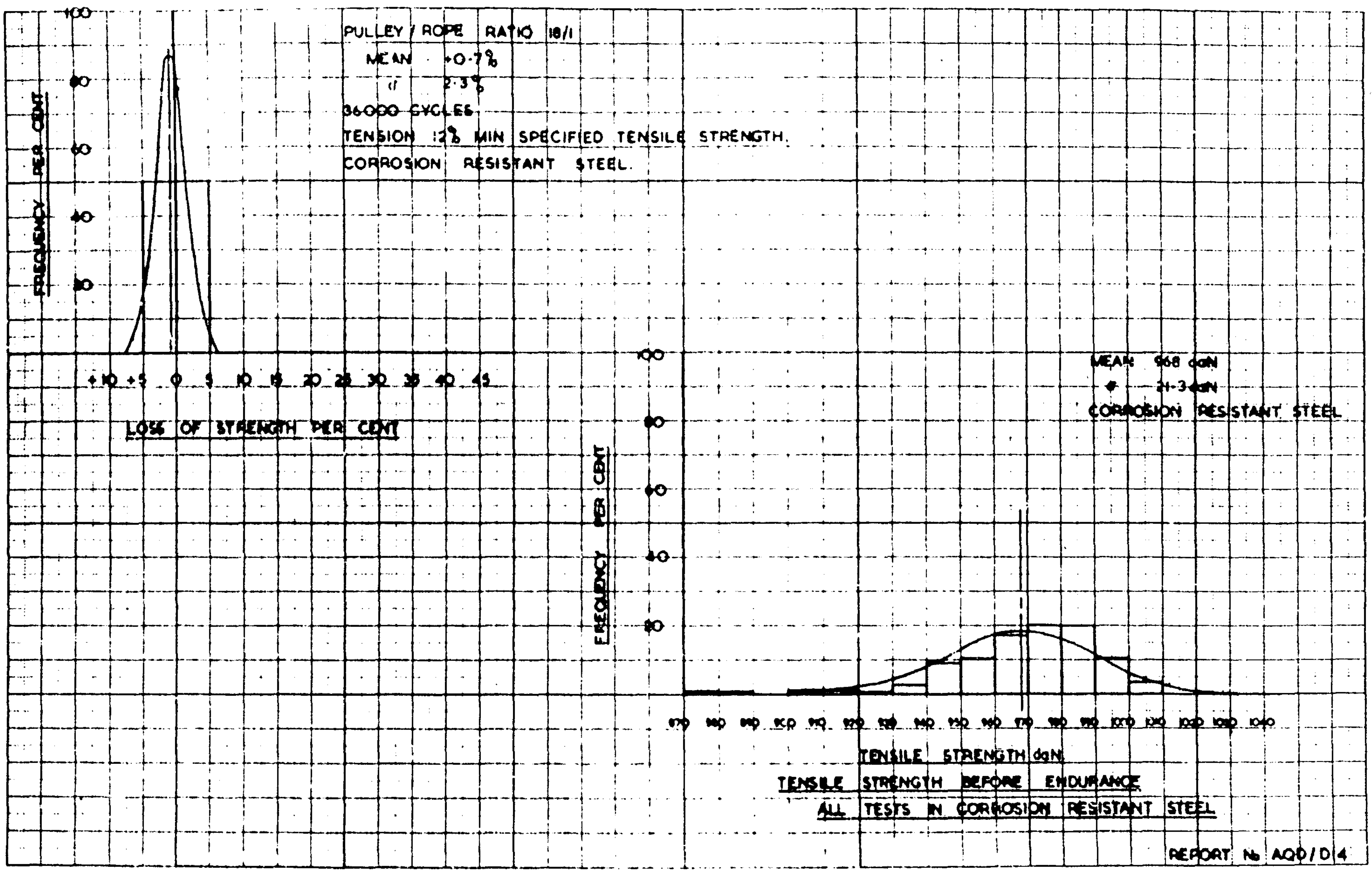
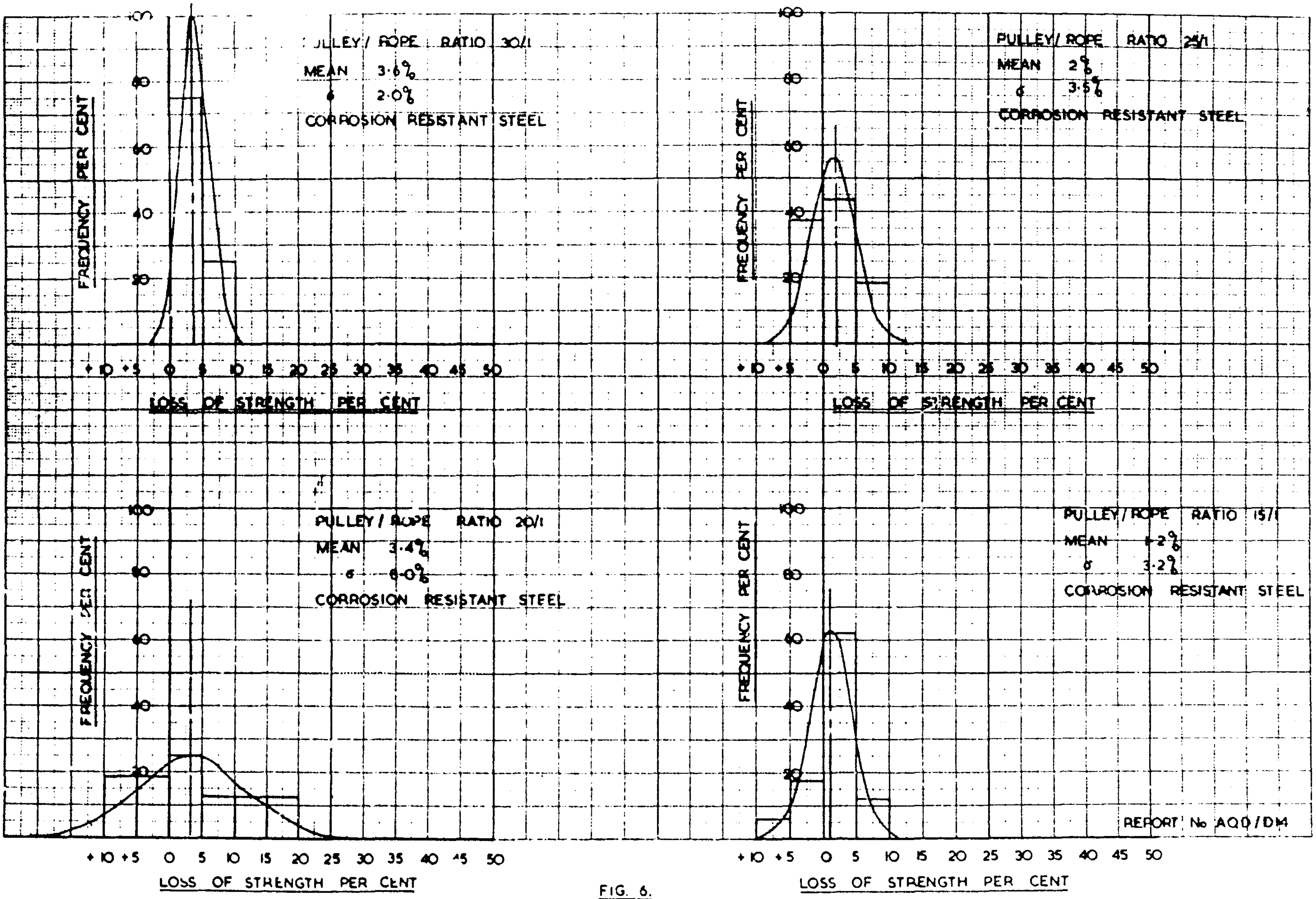

PULLEY / ROPE RATIO 18/1
MEAN +0·7%
" 2·3%
36000 CYCLES
TENSION 12% MIN SPECIFIED TENSILE STRENGTH.
CORROSION RESISTANT STEEL.
FREQUENCY PER CENT
100
80
60
40
20
+10 +5 0 5 10 15 20 25 30 35 40 45
LOSS OF STRENGTH PER CENT
MEAN 968 daN
" 21·3 daN
CORROSION RESISTANT STEEL
FREQUENCY PER CENT
100
80
60
40
20
870 880 890 900 910 920 930 940 950 960 970 980 990 1000 1010 1020 1030 1040
TENSILE STRENGTH daN
TENSILE STRENGTH BEFORE ENDURANCE
ALL TESTS IN CORROSION RESISTANT STEEL
REPORT No AQD/D 4

FIG. 5.



PULLEY / ROPE RATIO 30/1
MEAN 3·6%
σ 2·0%
CORROSION RESISTANT STEEL
FREQUENCY PER CENT
LOSS OF STRENGTH PER CENT
PULLEY / ROPE RATIO 25/1
MEAN 2%
σ 3·5%
CORROSION RESISTANT STEEL
PULLEY / ROPE RATIO 20/1
MEAN 3·4%
σ 6·0%
CORROSION RESISTANT STEEL
PULLEY / ROPE RATIO 15/1
MEAN 1·2%
σ 3·2%
CORROSION RESISTANT STEEL
REPORT No AQD/DM

FIG. 6.

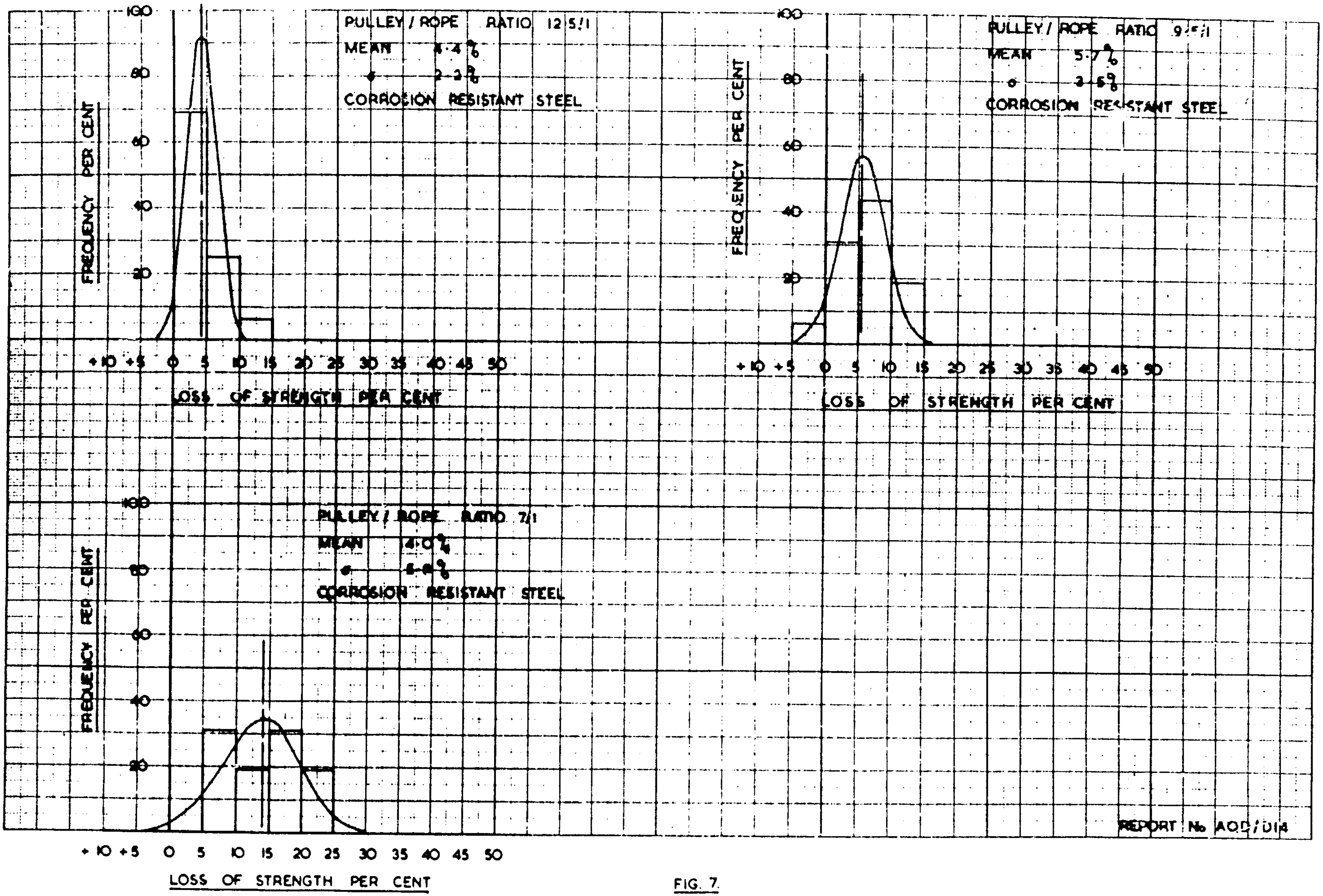

PULLEY / ROPE RATIO 12.5/1
MEAN
σ
CORROSION RESISTANT STEEL
FREQUENCY PER CENT
100
80
60
40
20
+10 +5 0 5 10 15 20 25 30 35 40 45 50
LOSS OF STRENGTH PER CENT
PULLEY / ROPE RATIO
MEAN 5·7 %
σ
CORROSION RESISTANT STEEL
FREQUENCY PER CENT
100
80
60
40
20
+10 +5 0 5 10 15 20 25 30 35 40 45 50
LOSS OF STRENGTH PER CENT
PULLEY / ROPE RATIO 7/1
MEAN 14·0 %
σ
CORROSION RESISTANT STEEL
FREQUENCY PER CENT
100
80
60
40
20
+10 +5 0 5 10 15 20 25 30 35 40 45 50
LOSS OF STRENGTH PER CENT
REPORT No AOD/014

FIG. 7.

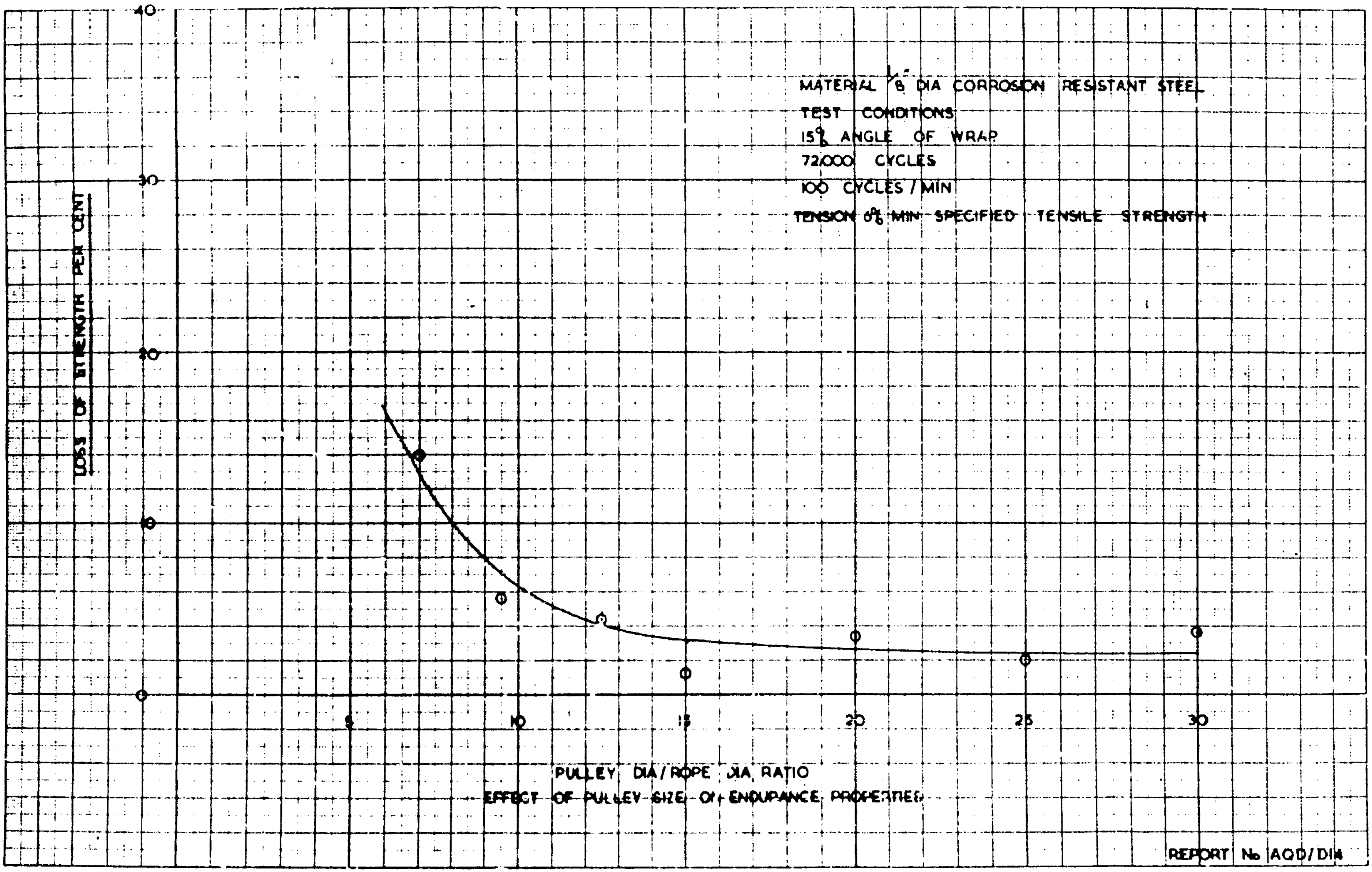

MATERIAL 1/8" DIA CORROSION RESISTANT STEEL
TEST CONDITIONS
15% ANGLE OF WRAP
72,000 CYCLES
100 CYCLES / MIN
TENSION 0% MIN SPECIFIED TENSILE STRENGTH
LOSS OF STRENGTH PER CENT
40
30
20
10
0
5
10
15
20
25
30
PULLEY DIA / ROPE DIA RATIO
EFFECT OF PULLEY SIZE ON ENDURANCE PROPERTIES
REPORT No AQD/DI4

FIG. 8

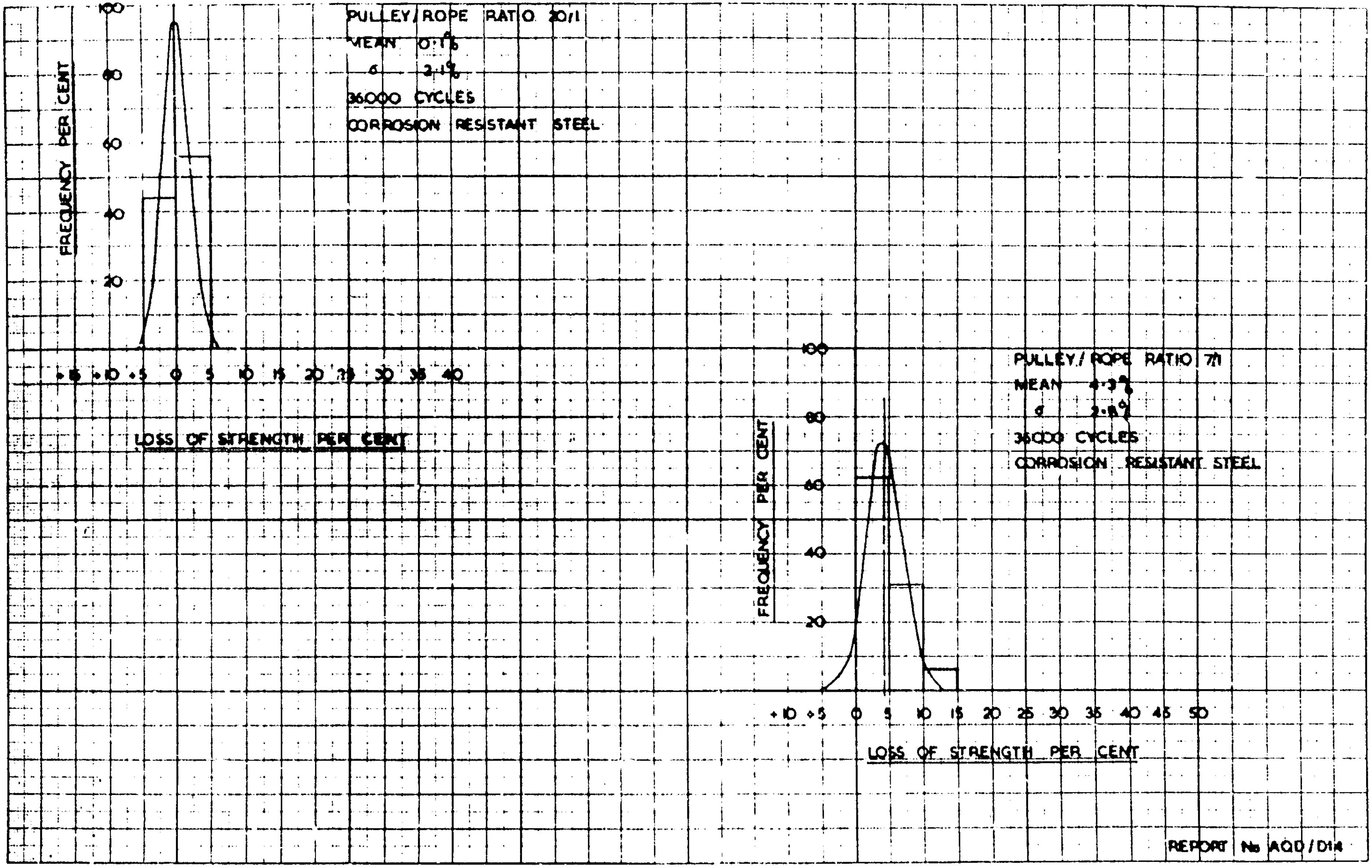
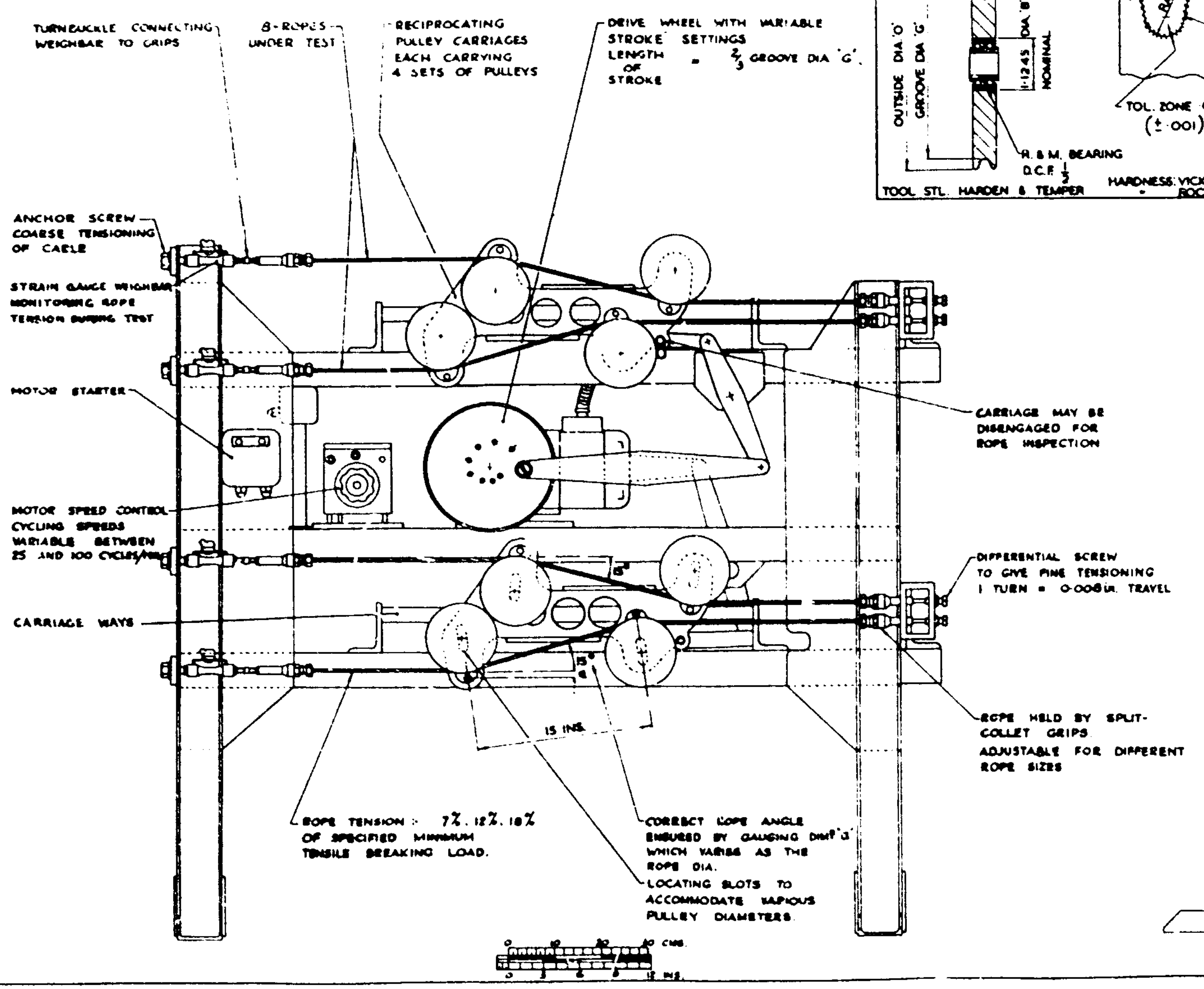

PULLEY/ROPE RATIO 20/1
MEAN 0·1%
σ 2·1%
36000 CYCLES
CORROSION RESISTANT STEEL
FREQUENCY PER CENT
100
80
60
40
20
+15 +10 +5 0 5 10 15 20 25 30 35 40
LOSS OF STRENGTH PER CENT
PULLEY/ROPE RATIO 7/1
MEAN 4·3%
σ 2·8%
36000 CYCLES
CORROSION RESISTANT STEEL
FREQUENCY PER CENT
100
80
60
40
20
+10 +5 0 5 10 15 20 25 30 35 40 45 50
LOSS OF STRENGTH PER CENT
REPORT No AQD/D14

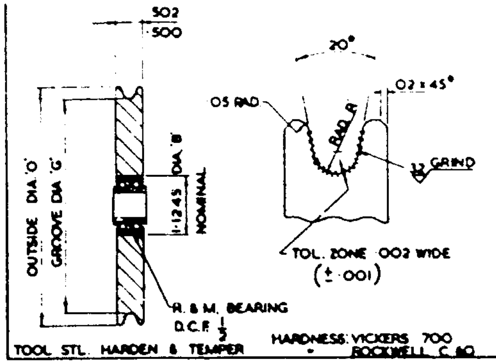
FIG. 9.

DEV/100/53

THIRD ANGLE PROJECTION.

A.Q.D ENDURANCE TEST MACHINE





ITEM Nº	RAD 'R'	GROOVE DIA 'G'	OUTSIDE DIA 'O'	ROPE DIA	PULLEY/ROPE RATIO
1	·0672	2·25	2·58	1/8	18
2	·0672	2·5	2·83	1/8	20
3	·0672	2·75	3·08	1/8	22
4	·1007	3·375	3·875	3/16	18
5	·1007	3·75	4·25	3/16	20
6	·1007	4·125	4·625	3/16	22
7	·1344	4·5	5·15	1/4	18
8	·1344	5·0	5·65	1/4	20
9	·1344	5·5	6·15	1/4	22

32 ALL OVER.

DIA 'G' & DIA 'B' DATUM ·002 DIA CONC. TOL.

DIA 'B' $^{·0004}_{·0009}$ INTERFERENCE FIT WITH BEARING

PULLEY/ROPE RATIO = $\frac{\text{DIA 'G'}}{\text{ROPE DIA}}$

R = $\frac{\text{ROPE DIA}}{2}$ x 1·075

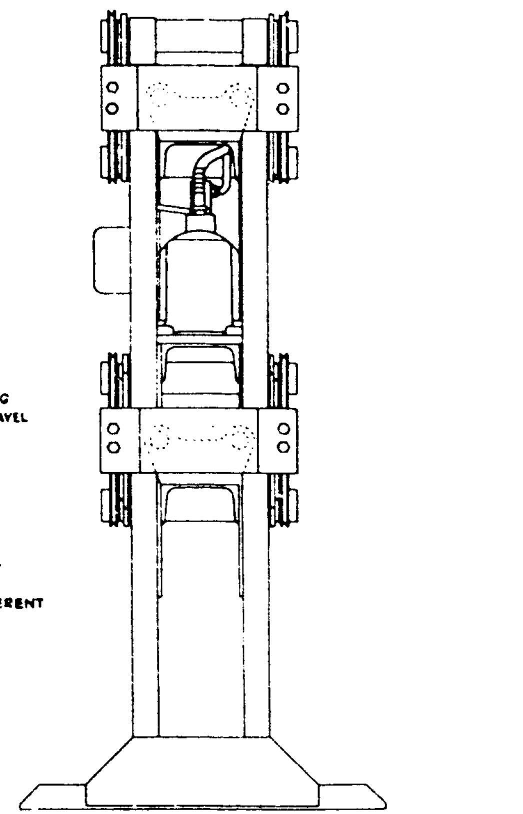


FIG 10 Report Nº A.Q.D. D14